

Effects of power electronics devices on the energy quality of an administrative building

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ABSTRACT

This paper proposes the analysis of the effects of power electronics devices on the energy quality of an administrative building. For the study a method is applied that allows the analysis of the main problems of energy quality such as voltage variation, harmonics, flicker, and the effect of harmonics on the power factor. As a case study, the offices of an administrative building were used, where the measurements of the main energy quality parameters were carried out for a week. The results showed the presence of current harmonics and flicker problems due to non-linear loads such as the frequency inverters that drive the motors of the elevators and escalators, as well as the LED lamps. These problems cause systematic damage to the lighting system, UPS and improper correction of the power factor. The study also demonstrates the need to deepen the effects of energy quality not only in the industrial and residential sectors. In addition, attention must be paid to the tertiary sector, specifically to administrative buildings.

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1. INTRODUCTION

Currently, the efficient use of energy is closely linked to cleaner production and sustainable development [1]. Among consumers of energy globally, electricity represents 18.8% of fuel consumption [2] and produces 42% of CO₂ emissions [3], with a projection of continuous growth in demand [4]. For this reason, special attention should be paid to its efficient use.

In recent times, new forms of production and consumption of electricity have been developed, with an increase in the use of electronic devices that have increased the problems of energy quality [5-7]. Among these equipment are static power converters, discharging devices in the form of electric arcs, saturated magnetic devices and uninterruptible power systems (UPS) [8-10]. There are several studies where the negative effects of these equipment on the functioning of the electrical system and its components are analyzed, such as the reduction of the useful life and the increase of the energy losses.

In [11] the increase in the harmonics that occurs in an industrial electrical system where PWM inverters predominate is evaluated, and it is demonstrated how the harmonics reach high values that affect the operation of motors, transformers and capacitors. The reduction in the useful life of the induction motors due to the overheating produced by the harmonics generated by the electronic devices is studied in [12-14]. In [15] the increase in copper losses of the motors produced by the PWM inverters is analyzed, while in [16, 17], the discharge of current in the bearings caused by these devices is evaluated.

The negative effects due to the combination of the harmonics and the voltage imbalance in the operation of the motors are analyzed in [18]. In [19] emphasis is placed on the increase in the oscillation of the torque ripple and in the vibrations produced by both phenomena.

The studies developed in [20, 21], focus on the increasing affectation that occurs in the transformers as a result of the increase of the non-linear loads that they feed. In [20, 22] it is analyzed the overheating in the iron and the reduction in the useful life of a transformer that feeds a residential circuit with predominance of electronic loads.

One of the main components of the electrical system that is being harmed the most with the increase of electronic devices are the capacitors. In [23] the increase of the temperature, the noise and the affectation in the dielectric elements of the capacitors produced by the harmonics are studied. The resonance effect is studied in [24] and it is demonstrated how the useful life of these elements can be significantly reduced by operating in an electrical system with distorted waves.

The studies on energy quality mentioned, and others such as those reported in [25-28] focus on the electric power system, industrial and residential sector, however, in no case the quality of energy in administrative buildings is analyzed. Therefore, this paper analyzes a new performance evaluation of the energy quality in administrative buildings.

Buildings are an important objective in energy efficiency studies since they consume 40% of total energy and emit 30% of global greenhouse gases [29-31]. Administrative or office buildings, due to their constructive characteristics and their use, have a high incidence in the referred consumption [32, 33]. This consumption is mainly due to the intensive use of air conditioning systems [34, 35].

In the city of Barranquilla, Colombia, where the study is carried out, the field of construction maintains a positive dynamic, which is reflected in the growth that the city has had in recent years. This growth produces an increase in the consumption of electrical energy, due to the need to satisfy building requirements and user comfort [36].

The use of non-linear loads with significant energy consumption such as frequency inverters for the drive of elevator motors [37], air conditioning systems with inverter technology [38], LED lamps [39] and UPS [40], among others have also increased in buildings. Due to these aspects, this work is important because aims to evaluate the behavior of the quality of energy in an administrative building.

The paper is structured as following. The characteristics of the energy quality problems analyzed, and the method used for the study are described in section 2. Section 3 presents and analyzes the results obtained in a case study in the offices of an administrative building with loads non-linear, while the study conclusions are presented in section 4.

2. RESEARCH METHOD

The circuits that feed the administrative areas can be affected by the problems of energy quality that are commonly presented in electrical distribution systems such as voltage variation, flickers, harmonic distortion and displacement power factor [11, 18, 41]. The main characteristics of these phenomena that were evaluated in the study are described below.

2.1. Voltage variations

The voltage variation is the changes in the magnitude (amplitude) of the steady-state voltage when the system operates at nominal frequency (60 Hz) [41]. A low voltage circuit has voltage variation problems if the effective value is outside the range of $\pm 10\%$ in relation to the nominal value for a time greater than one minute [41].

2.2. Flickers

This phenomenon is defined from the perception of flicker in electric lights, caused by changes in the effective value of the voltage. The parameters used for the evaluation of flicker are the short-term perception (Pst), obtained by periodic measurements every ten minutes and the long-term perception (Plt), obtained by periodic measurements of two hours [41, 42]. The Plt is obtained from Pst, according to (1) [42].

$$Plt = \sqrt[3]{\frac{1}{12} \times \sum_{j=1}^{12} Pst_j^3} \quad (1)$$

Under steady-state operating conditions, Pst and Plt must comply with the limits shown in Table 1 for a voltage below 69 kV [42].

Table 1. Compatibility levels for Pst and Plt in power systems of voltage below 69 kV

Compatibility levels	
Pst	1.0
Plt	0.8

2.3. Harmonic distortion

A harmonic is a component of the harmonic distortion in the waveform of voltage and current produced primarily by non-linear devices. Harmonics are defined as a sinusoidal component of a frequency that is an integral multiple of the fundamental frequency of the electric network [43, 44]. A distorted wave of voltage or current is the result of the sum of harmonics.

The fundamental parameters for the harmonic characterization are: total harmonic distortion of voltage (THDv) and current (THDi), the total demand distortion (TDD) individual voltage distortion (IDv) and individual current distortion (IDi). These parameters are calculated with (2), (3), **Error! Reference source not found.**, (5) and (6) [43, 44].

$$\text{THDv} = \frac{\sqrt{\sum_{h=2}^{40} V_h^2}}{V_1} \quad (2)$$

$$\text{THDi} = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_1} \quad (3)$$

$$\text{TDD} = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_L} \quad (4)$$

$$\text{IDv} = \frac{V_h}{V_1} \quad (5)$$

$$\text{IDi} = \frac{I_h}{I_1} \quad (6)$$

where h is the order of the higher harmonics and I_L is the maximum load current or peak demand.

According to the IEEE Standard Std 1159-2014 [44] for voltage lower than 1 kV and the ratio between the short-circuit current (I_{sc}) and maximum demand (I_L) in the range between 100 and 1000, the THDv, IDv, TDD and THDi must not exceed the values presented in Table 2. For the evaluation of IDi, the limits values showed in Table 3 are considered for different harmonic intervals corresponding to the relationship between I_{sc} and I_L indicated [44].

Table 2. Limits of THDv, IDv and TDD [44]

Parameters	THDv	IDv	TDD	THDi
Limits (%)	8%	5%	15%	20%

Table 3. Current distortion limits for systems from 120 V to 69 kV [44]

Individual order of harmonics			
I_{sc}/I_L	$3 \leq h < 11$	$11 \leq h < 17$	$17 \leq h < 23$
100<1000	12.0	5.5	5.0

2.4. Displacement power factor

The power factor is a parameter that relates the active power (P) and the apparent power (S). The component of the displacement of the power factor (DPF) is the relation between the indicated powers of the fundamental component wave. the (7) shows the corresponding equation based on the power triangle [10].

$$\text{DPF} = \frac{P}{S} = \cos\theta \quad (7)$$

The parameter S for the fundamental component of the voltage and current wave is determined as:

$$S = \sqrt{P^2 + Q^2} \quad (8)$$

For systems with distorted waves where harmonics are added to the fundamental wave, the power triangle is modified and the apparent power is calculated according to (9) [43].

$$S = \sqrt{P^2 + Q^2 + D^2} \quad (9)$$

Under these conditions, the power factor is defined as a True Power Factor (TPF). Its definition represented in (10) is obtained by replacing (9) in (7) that allows analyzing the influence of harmonics on the power factor.

$$\text{TPF} = \frac{P}{\sqrt{P^2 + Q^2 + D^2}} \quad (10)$$

2.5. Steps of method

In the present study, the following steps were established to study the quality of energy:

- Measurement in the main board with a power analyzer of the electrical parameters of voltage, Plt, harmonics and displacement and true power factor.
- Evaluation of the voltage graph obtained in the measurements. Analyze if the maximum voltage values are within $\pm 10\%$ of the nominal voltage of the transformer.
- Analysis of the Plt graph obtained in the measurements. Evaluate if the measured values are below 0.8 within the 95% percentile.
- Analysis of harmonic distortion considering the following parameters:
 - Evaluation of the THDv graph obtained in the measurements and verify that the values are below 8%.
 - Evaluation of the THDi graph and verify that the values are below 20%.
 - Evaluation of the individual harmonics and TDD and compare the values with the limits of 15% presented in Table 3.
- Evaluation of the DPF and TPF measured and compare the values in relation to 0.9 which is the limit established by the energy supply companies. It is also determined the incidence of the harmonics on the power factor.

3. RESULTS AND DISCUSSION

The study of energy quality was carried out in the offices of a company that occupy two floors of a ten-story business complex in Barranquilla city, Colombia. The company offices have 20 workstations with computers, 20 panel luminaires with 50W LED lamps and a 5-ton central air conditioner. The supply circuit of these offices is influenced by the network of the building that presents several non-linear loads such as frequency variators and LED lamps, belonging to the common area of the complex and to the escalators and elevators. These loads cause distortions in the waveform and disturbances in the electrical system, which can be the cause of the damage to the luminaires of the offices and the shots to the protections of the UPS that occurs systematically.

The measurements were made with a power analyzer Metrel model MI2892. The measurements were carried out for seven days with data recording period every ten minutes. The instrument was placed in the main switch of the distribution board. In Figure 1 the one-line diagram with the connection point of the power analyzer is shown. Next, the evaluation results of the measured parameters are analyzed.

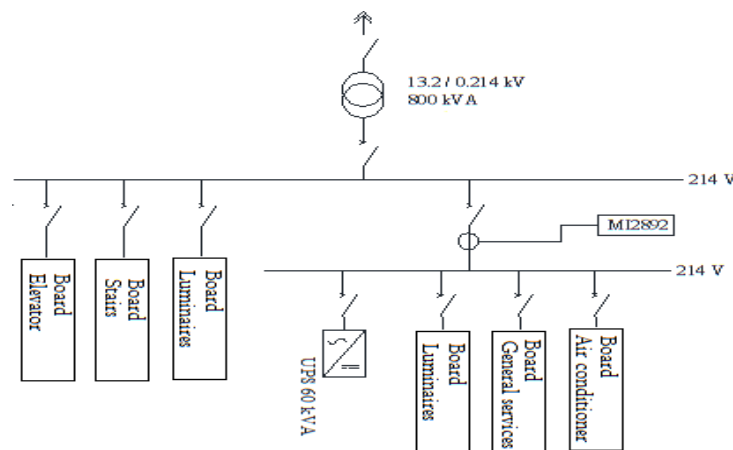


Figure 1. One-line diagram

3.1. Analysis of voltage variation

In Figure 2 the voltages measured in the three lines (U12, U23 and U31) are shown. The average of the voltages was of 218.63 V, while the maximum and minimum values were of 229.49 V and 210.81 V respectively. Considering that the nominal voltage in the network analyzed is 214 V, it can be concluded that the average voltage is 2.16% greater than the nominal voltage, the maximum voltage is 7.24% higher and the minimum is 1.49% lower, therefore, they are within the established limit of $\pm 10\%$.

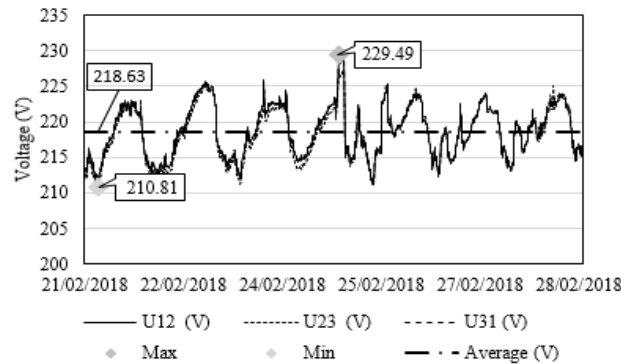


Figure 2. Measured voltage

3.2. Analysis of flicker

In Figure 3 (a) the Plt of the three lines is shown. As can be seen, most of the values are below 0.8 which is the limit established in Table 1, while some values do exceed this value. In Figure 3 (b) it can also be observed, by means of a percentile graph that the values below the limit comprise 86.7% of the data. This result implies a problem of energy quality due to the presence of flicker, since it is expected that the values must be less than 1 in 95% of the data at least.

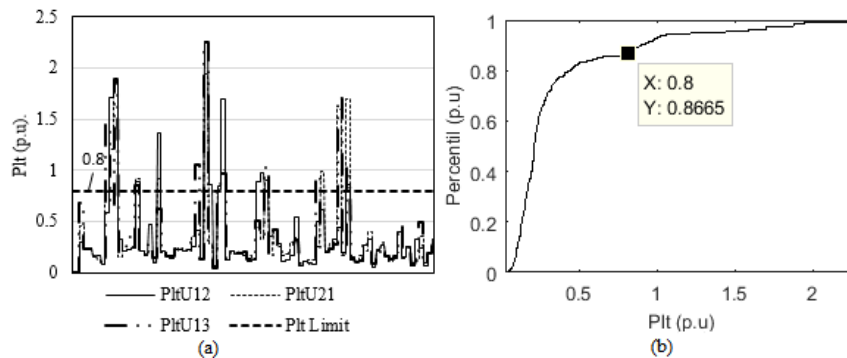


Figure 3. Measurement of Plt, (a) graphic of Plt, (b) percentile graph for Plt measurements

3.3. Analysis of THDv and IDv

In Figure 4 (a) the THDv measurements are shown, while in Figure 4 (b) the behavior of the individual voltage harmonics can be observed. In these graphs, voltage harmonic problems are not evidenced since the measured values are lower than 8% and 5% respectively, limits established by the standards and shown in Table 2. For the THDv, the maximum value was 5.69% while in the individual harmonics it was 1.75%.

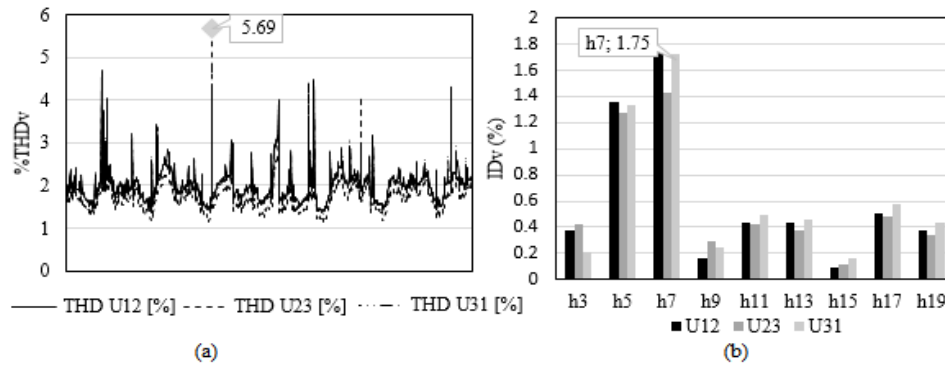


Figure 4. Measurement of THDv, (a) graphic of THDv, (b) bar graphs of individual voltage harmonics

3.4. Analysis of THDi

Figure 5 (a) represents the measured THDi values. In this case, most of the data are above 20%, the limit value established by the standards and presented in Table 1. In Figure 5 (b) it is observed in the percentile graph, that 76.3% of the data exceed the limit, therefore, a problem of harmonics in the current caused by non-linear loads is evident.

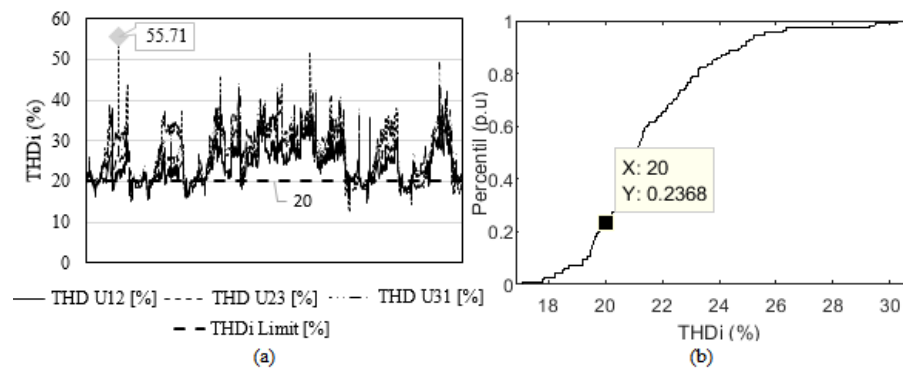


Figure 5. Measurement of THDi, (a) graphic of THDi, (b) percentile graph for THDi measurements

3.5. Analysis of TDD and IDi

The measured TDD values are shown in Figure 6 (a). According to the IEEE Std 519-2014 [44] these values must be less than 15%, because the I_{sc}/I_L ratio is between $100 < 1000$. In Figure 6 (b) the percentile graph is represented. As noted, 18% of the samples during the measurement period are above the percentage recommended by the standard. This behavior represents a problem of energy quality due to harmonics of current since the standard establishes that the values must be lower than the limit in 95% of the registered samples.

The values of individual harmonics by a bar graph are presented in Figure 7. Comparing these values with the limits of Table 3, is showed that harmonics of 5th and 7th order with IDi values of 12.99% and 31.62% respectively, are above the limit of 12% indicated for the harmonics between 3rd and 10th level. In addition, the harmonic of order 11 with an IDi of 7% is above the limit of 5.5% established for the harmonics between 11th and 17th levels.

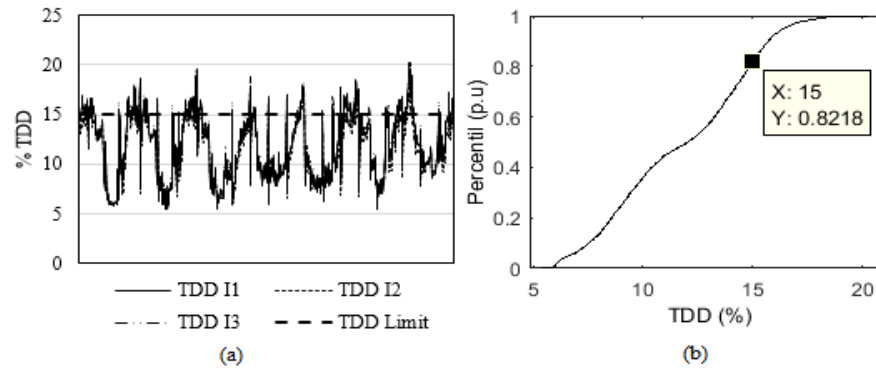


Figure 6. Measurement of TDD, (a) graphic of TDD, (b) percentile graph for TDD measurements

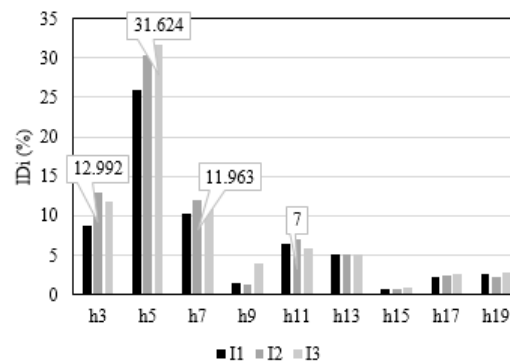


Figure 7. IDi bar graph

3.6. Analysis of power factor

The DPF and TPF are shown in Figure 8 (a) and (b) respectively. As can be seen, the two parameters are above 0.9 in most of the records thus fulfilling the requirements of the energy distribution company. The results also show that the TPF values of Figure 8 (b) are smaller than the DPF of Figure 9 (a), even with a record of 0.853 due to the effect of the harmonics. The zero values are due to interruptions in the power supply.

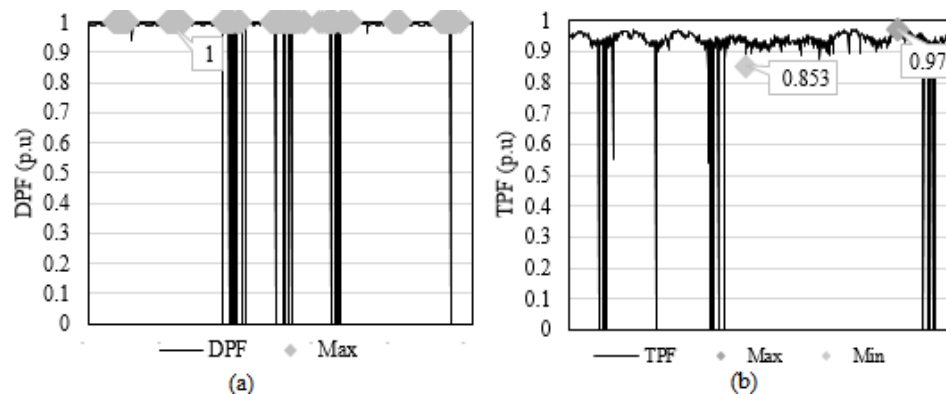


Figure 8. Measurement of power factor, (a) graphic of DPF, (b) graphic of TPF

3.7. Causes and effects of the disturbances identified

The results obtained show that the variable speed drives of the induction motors of the elevator and the escalators systems provoke the individual harmonics of the 5th and 7th order, which are the most generated by three-phase rectifiers [11, 45]. In addition, it was possible to demonstrate the production of harmonics by the LED lamps.

These identified problems could partially explain the problems that are systematically presented in the electronic boards of the lighting system due to the individual harmonics of zero sequence, and the problems presented by flickers in the luminaires. Finally, the power factor is affected by the presence of the harmonics, decreasing the real value. This produces false readings in the control equipment for reactive compensation, and therefore detracts injecting the reactive power needed for compensating the power factor of the system.

4. CONCLUSION

The present study demonstrates the need to focus the analysis of the effects of poor quality of energy not only in the electric power system, industrial and residential sector but also in the tertiary sector as in administrative buildings.

The results of the case study presented in an administrative building showed the affectation of the energy quality caused by the frequency inverters of elevator and escalators motors, as well as LED lamps. This was reflected in the parameters of the THDi, IDi, TDD and flicker, with values that exceeded the limits established by the standards.

It was possible to verify how the identified phenomena could be the causes of problems present in the installation of the building in the lighting systems, in the UPS and in the inadequate correction of the power factor. Due to this, the installation of passive filters is recommended to reduce the identified harmonics.

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